Unlock the Power of Your ROM

Presented By

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Thermal & Fluids Analysis Workshop
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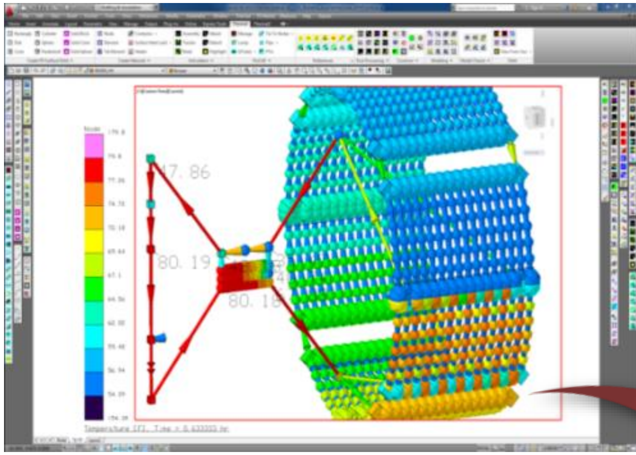
NASA Marshall Space Flight Center
Huntsville, AL

THERMAL & FLUIDS ANALYSIS WORKSHOP

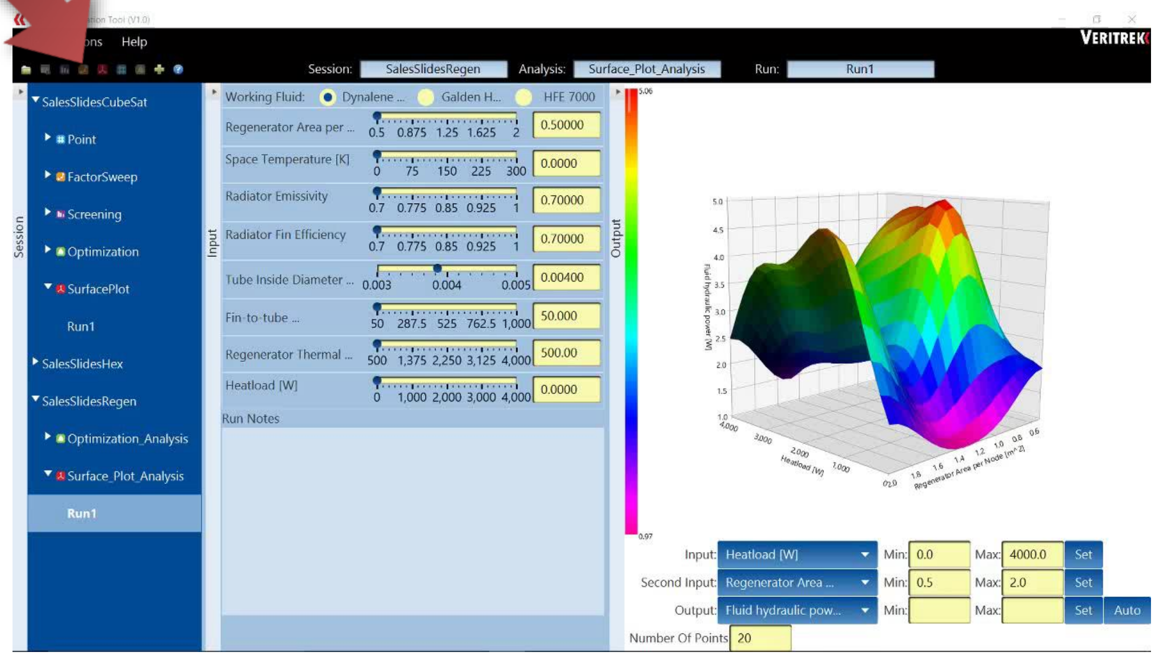
TFAWS
MSFC • 2017

Veritrek



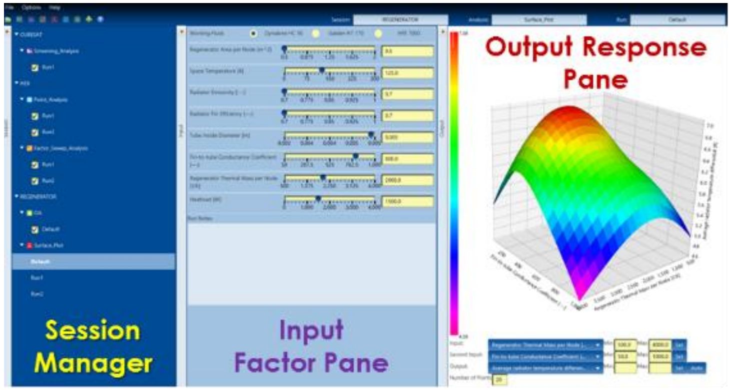
Thermal Desktop
Powerful thermal-fluid systems analyzer

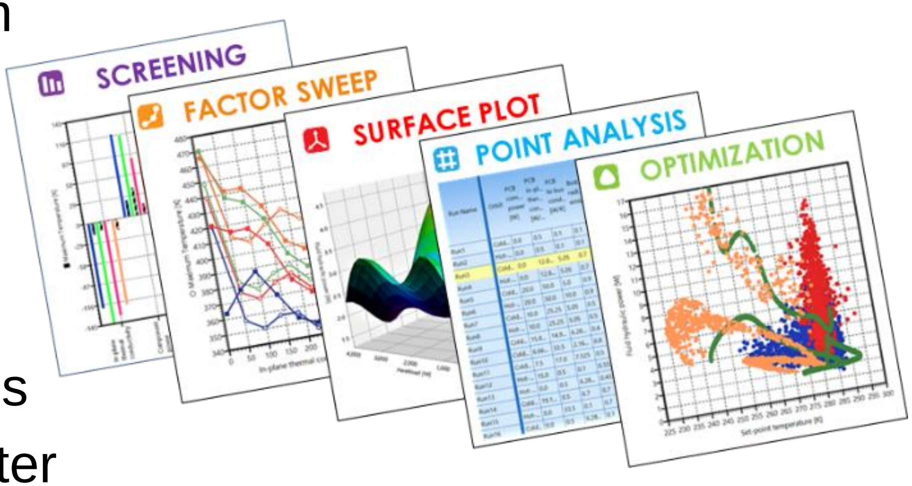
Veritrek Exploration Tool
1,000s of processed simulation results in seconds



Reduced-Order Models

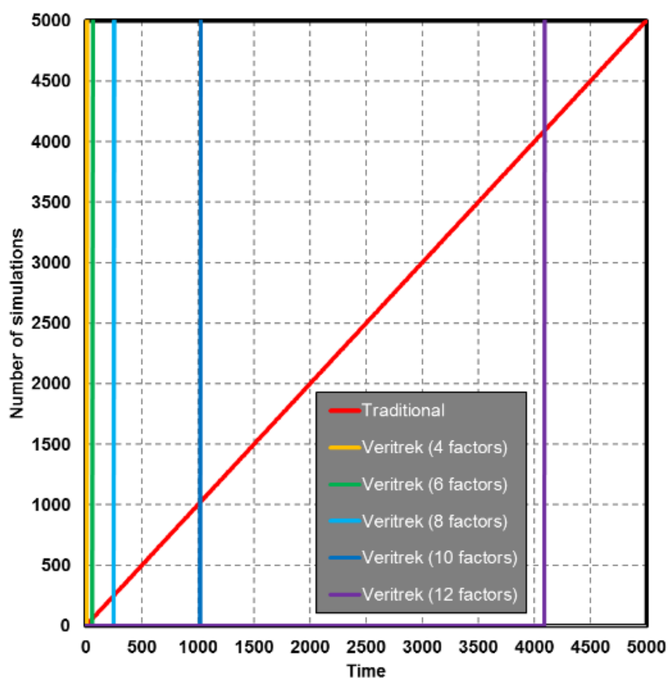
- ROMs enables faster, more effective exploration of your data.
  - Enables real-time results
  - Intuitive user interface encourages collaboration
  - More effective data exploration through advanced analysis capabilities
- Benefits
  - Reduce modeling costs
  - Enable more optimized designs
  - Improve schedules though faster analysis
  - Fosters collaboration
- Built for Thermal Desktop®

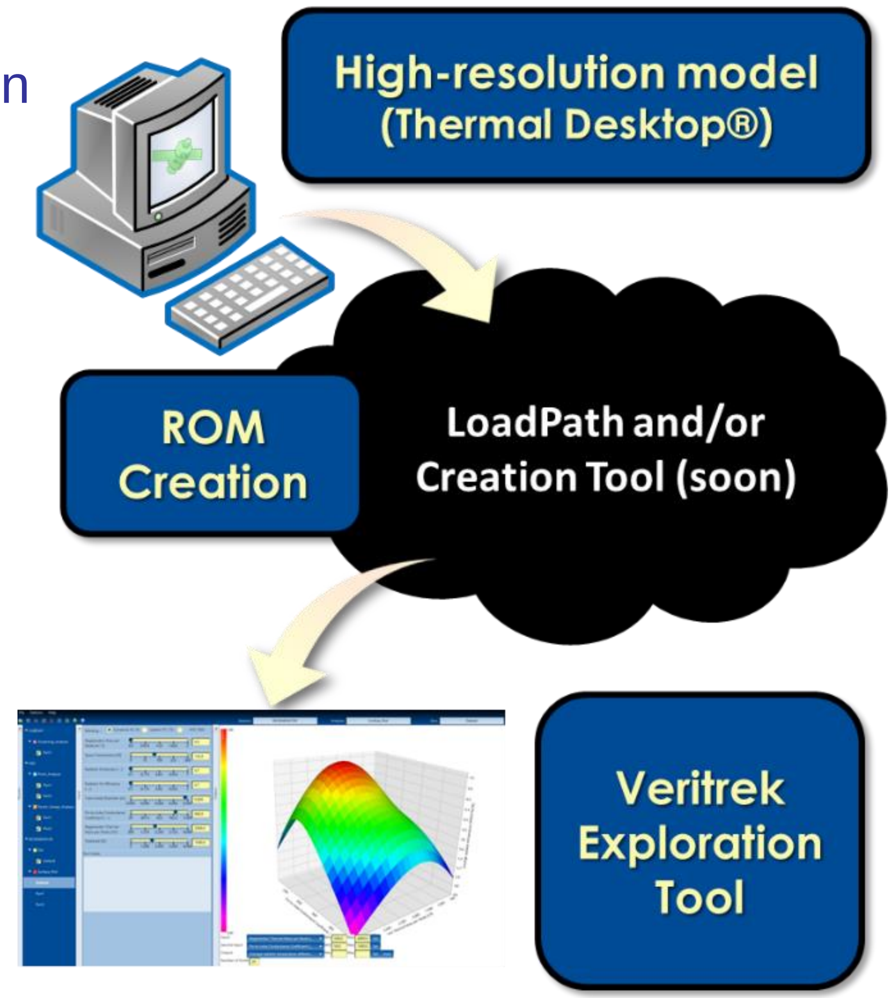




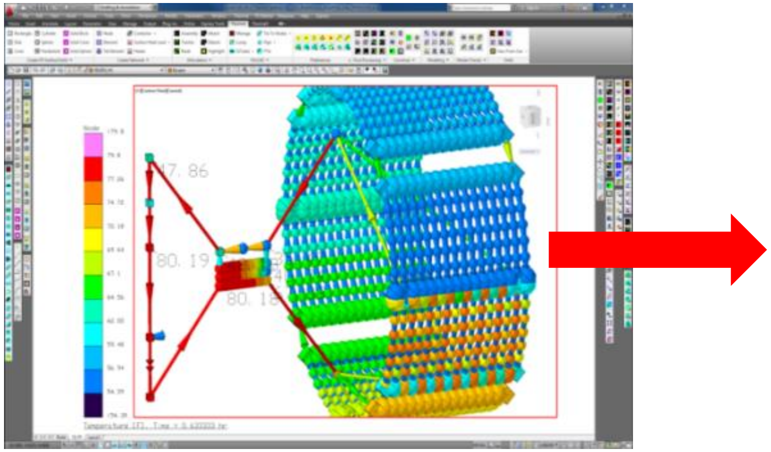
What is a ROM?

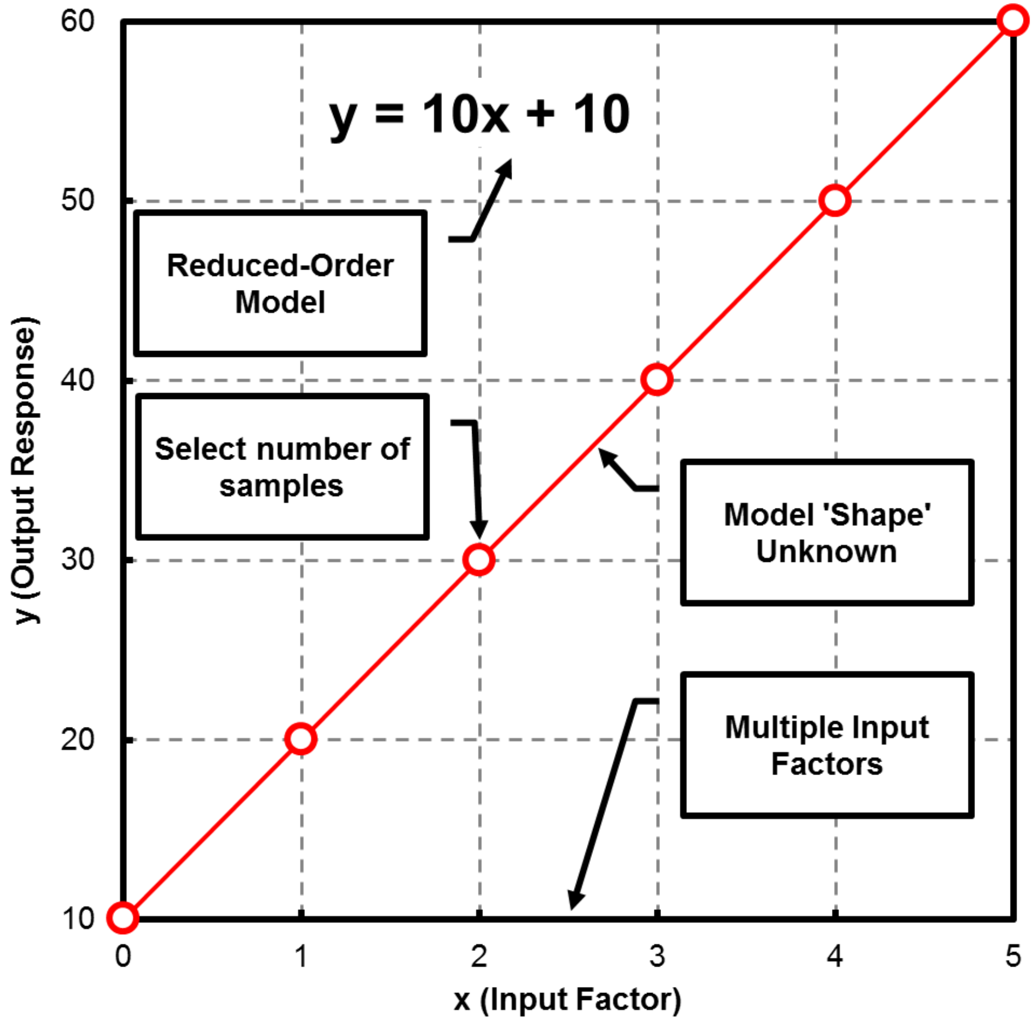
- An accurate surrogate of a high fidelity model
- Based on intelligent sampling then data fitting
- Sampling based on Latin Hypercube methods
- Data fitting based on Gaussian-Process methods





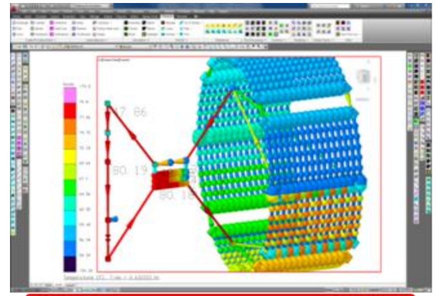
Sampling and Data Fitting

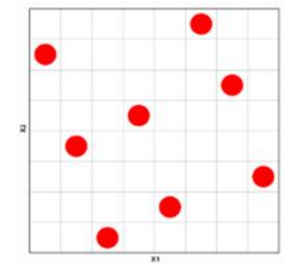




Approach

- Approach
  - Based on sample of computer simulations
  - Capture effects between sampling points
- Advantages
  - Fast computations
  - Useable by ‘non-trained’ personnel
- Disadvantages
  - Captures a limited set of possible variables
  - ROM creation time





High resolution model

Select sample points (Input Factors)

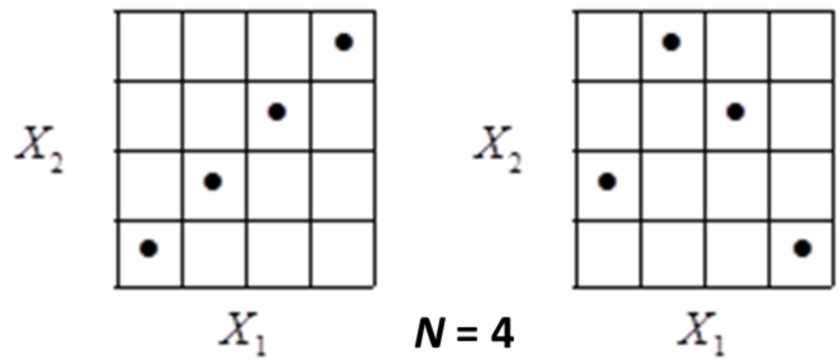
Run model at sampling points (monitor Output Responses)

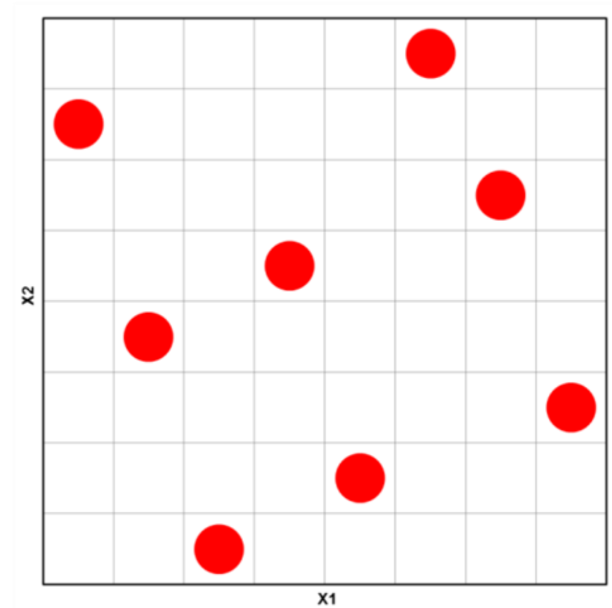
Develop ROM (Input Factors to Output Responses)

Test ROM (ROM versus Computer Simulations)

Sampling

- Latin Hypercube Sampling
- A method for efficiently filling a design space
- The range of each Input Factor (e.g. X) is divided into N intervals
  - N = number of samples
  - Each interval is used only once
- Maximize the minimum distance between points
- Using pseudo-Maximin Method
  - Maximize the minimum distance between sampling points



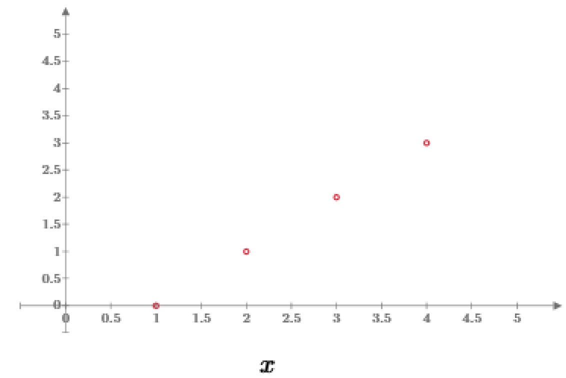


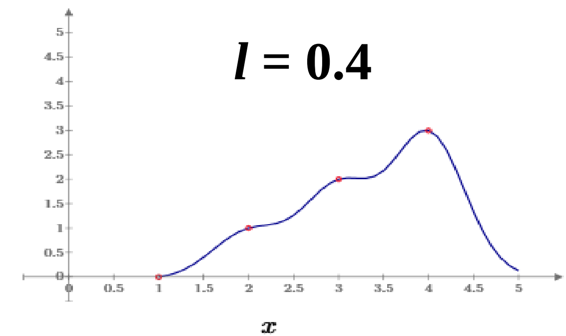
2 factors | 8 sampling points

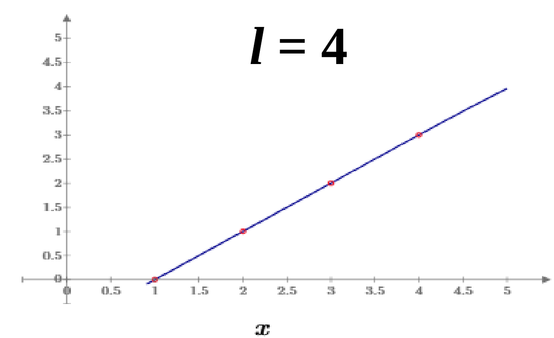
Data Fitting

- Gaussian Process
- Does not impose a specific model structure
  - E.g. ‘f(x) = mx + c’ not needed
  - Can fit a wide-range of data without prior knowledge of ‘shape’
- Based on training data
  - E.g. simulation results
  - Resulting covariance matrix populated using kernel function
  - Optimized hyperparameters needed
- Can fit data exactly; useful for computer simulations
- Provide confidence intervals

$$k(x_i, x_j) = v^2 \exp\left(\frac{\left\|x_i - x_j\right\|^2}{2l^2}\right)$$



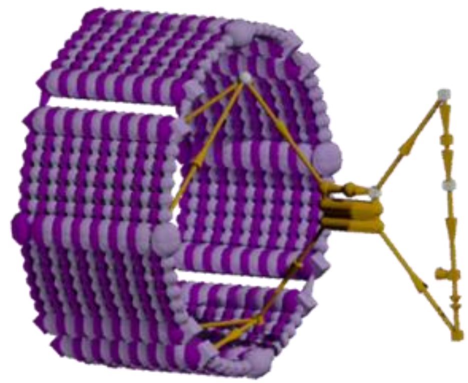




History

- 2009 - Initial work
- 2010 - “Development of a system design methodology for robust thermal control subsystems to support responsive space”, Dissertation.
- 2011 - Thermal control for ORS satellites, DoD SBIR Ph I
- 2012 - Thermal control for ORS satellites, DoD SBIR Ph II
- 2013 - Advanced spacecraft thermal modeling, NASA SBIR Ph I
- 2013 - Advanced spacecraft thermal modeling, NASA SBIR Ph II
- 2016 - “Reduced-order modeling for rapid thermal analysis and evaluation of spacecraft”, 46th AIAA Thermophysics Conference
- 2016 - “Reduced-order modeling for rapid thermal analysis and evaluation of spacecraft”, Thermal and Fluids Analysis Workshop.
- 2016 - “Reduced-order modeling for rapid thermal analysis and evaluation of spacecraft”, Spacecraft Thermal Control Workshop

AFRL
(2009-)



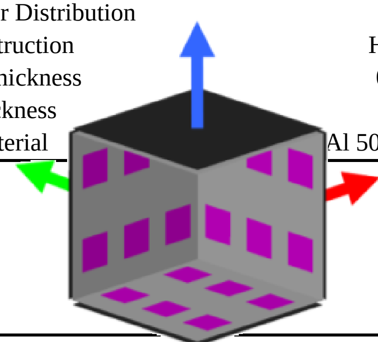
NASA
(2013-)

Commercial
(2015-)

Initial Work

- Evaluated approach using nominal satellite design
  - 1.0 x 1.0 x 1.0 m cubic satellite
  - Honeycomb construction
  - Body-mounted radiators
- Input factors (11 total)
  - 3 categorical (orbit/heat pipe/optimized placement)
  - 8 continuous
- Output responses (3 total)
  - Maximum orbital temperature
  - Minimum orbital temperature
  - Maximum temperature difference

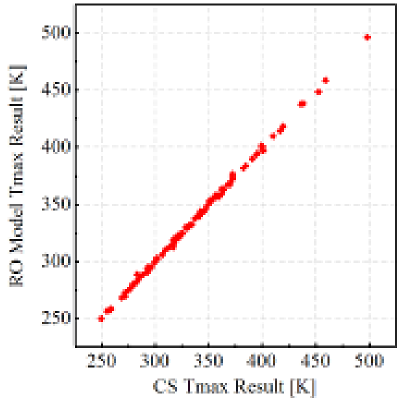
Factor	Factor Description
Satellite Shape	Cube
Satellite Size	1.0 m x 1.0 m x 1.0 m
Satellite Structure	Frame and Panel
Satellite Pointing	Nadir
Total Number of Components	36
Component Power Distribution	Case C
Panel Construction	Honeycomb
Facesheet Thickness	0.00127 m
Core Thickness	0.0254 m
Core Material	Al 5052 Honeycomb

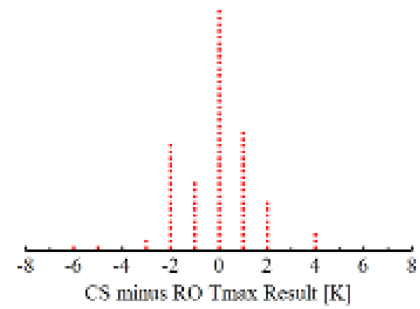


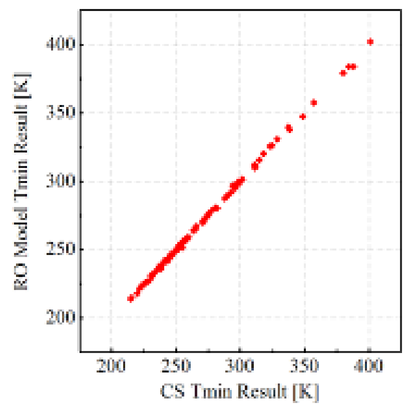
Label	Factor	Variable Name	Low Value	High Value
A	Orbit	ORBIT	Cold-case	Hot-case
B	Total Component Power	TOT_PWR	60 W	600 W
C	Component Side Dimension	C_DIM	0.1 m	0.2 m
D	Component Interface Heat Transfer Coefficient	C_I_CND	110 W/m^2-K	700 W/m^2-K
E	Facesheet Material Transverse Thermal Conductivity	F_T_CND	170 W/m-K	1000 W/m-K
F	Heat Pipes	HT_PIPE	0	10 per panel
G	Panel-to-Panel Thermal Conductance	P2P_CND	12 W/K	36 W/K
H	Surface Solar Absorptivity	EXT_ABS	0.123	0.561
I	Surface Longwave Emissivity	EXT_EMS	0.100	0.900
J	Global Component Distribution	GLBL_DIS	Nominal	Optimized
K	Local Component Placement	LCL_PLC	Nominal	Optimized

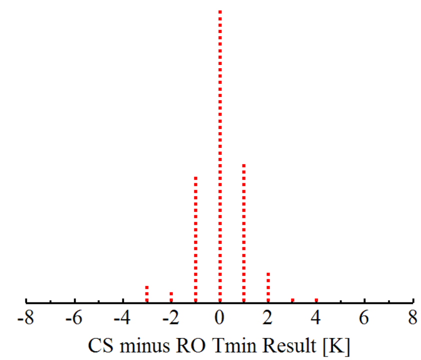
Initial Work

- Reduced-order model was developed
- Utilized Latin Hypercube / Gaussian Process
- ROM evaluated at 100 random test points
- ROM versus computer simulation (CS) results
- ROM provides good performance (i.e. dotplot results)
- Mean value near 0 K
- Standard deviations are acceptable

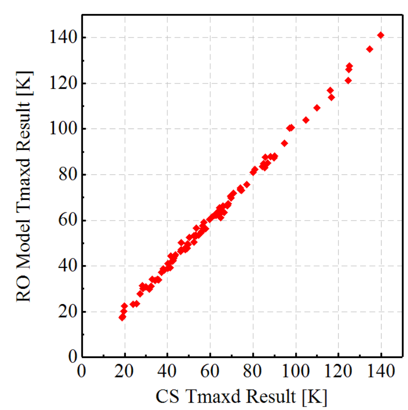


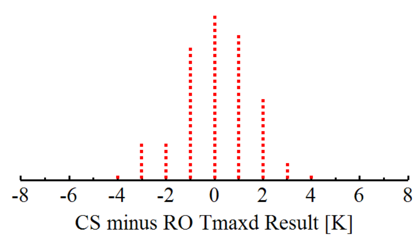






Response	Mean [K]	Standard Deviation [K]
Tmax	-0.1448	1.547
Tmin	0.06414	1.077
Tmaxd	0.08643	1.518





- Orion Crew Exploration Vehicle (CEV)
  - External fluid loop
  - Heat rejection system (radiators)
  - Control setpoint (FLOW.487)
- Results
  - CS results compared to ROM
  - Residual mean (trueness)
  - Standard deviation (precision)
  - Temperature: 1.6 K max residual mean and 5.0 K standard deviation
  - Power: 0.2 W max residual mean and 1.93 W standard deviation
  - Did poor job of replicating output responses with discontinuities

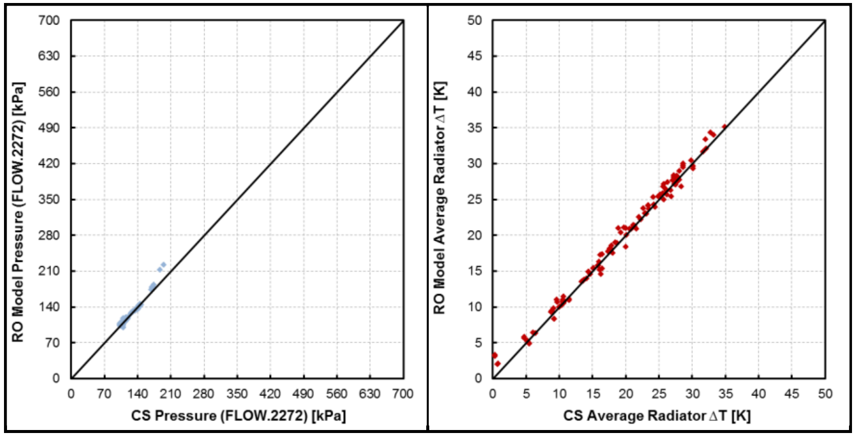
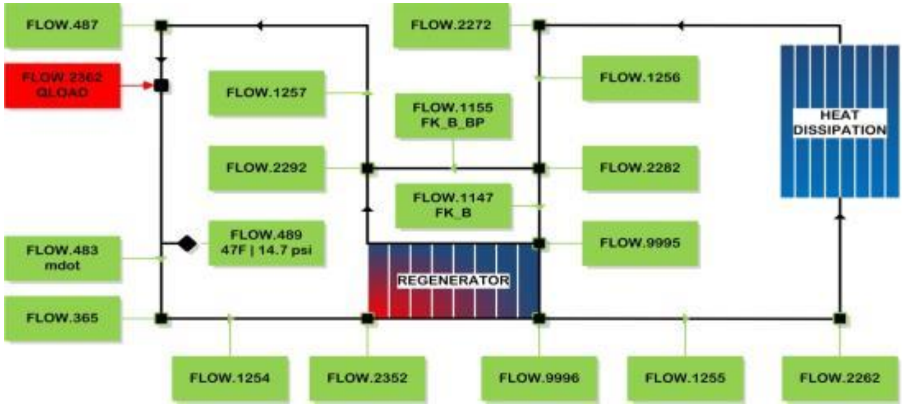
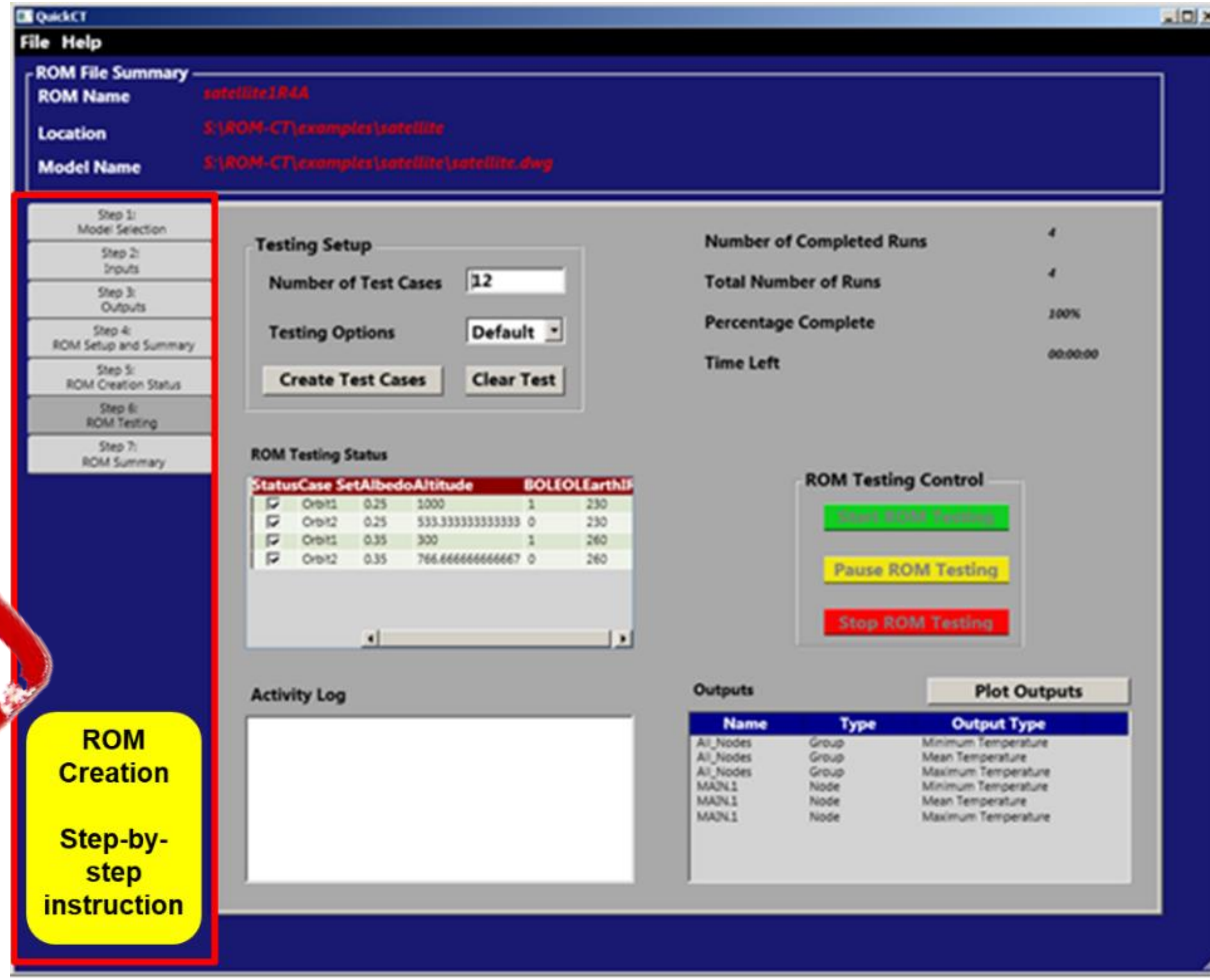


Figure 1: Galden HT 170 RO versus CS Plots for Two Output Responses: Pressure (FLOW.2272) and Average Radiator ΔT (768 LH Sample Points)

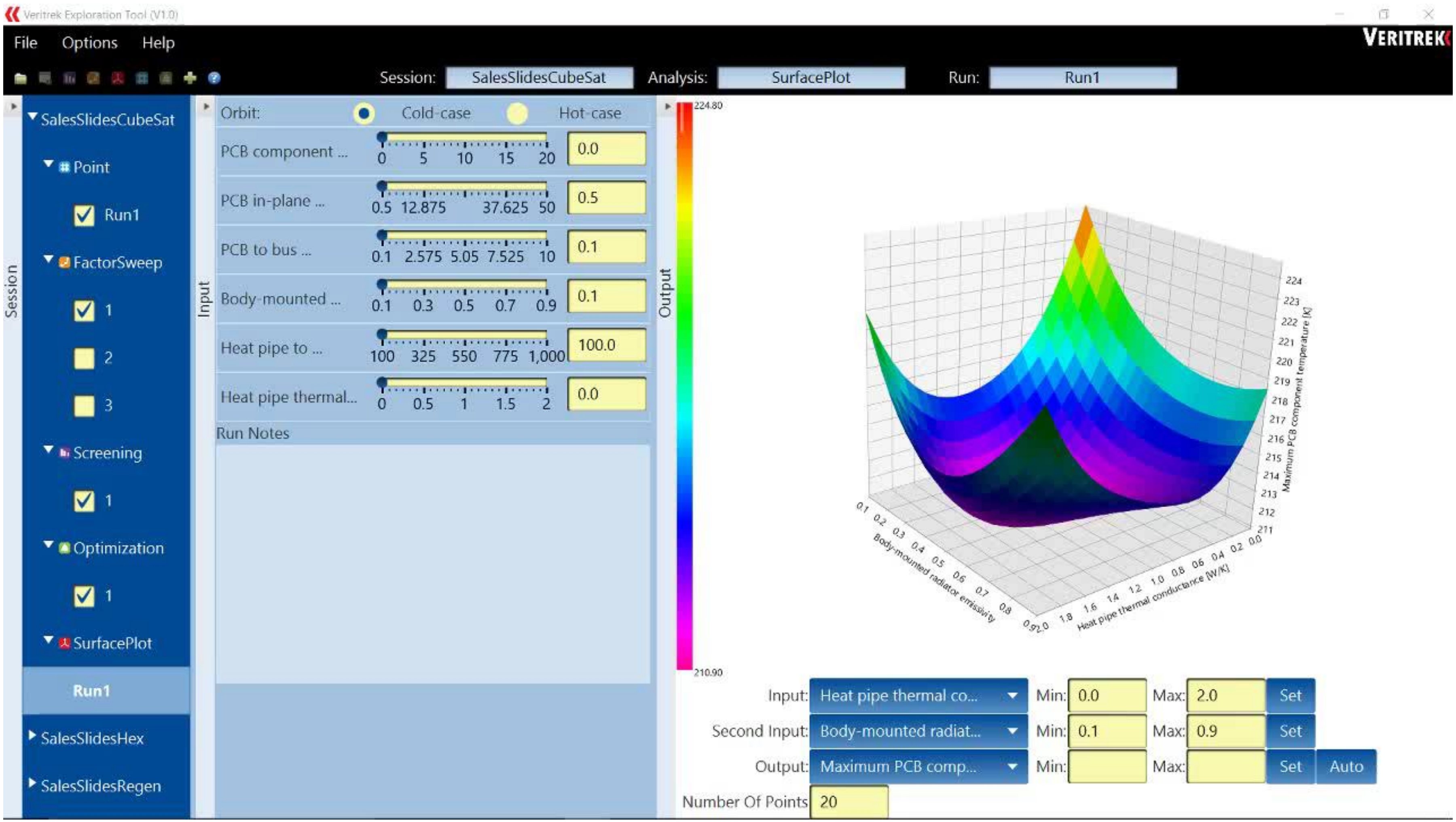


Creation Tool

- Alpha version
- Beta version
  - TD 6.0 API
  - Improved sampling/data fitting

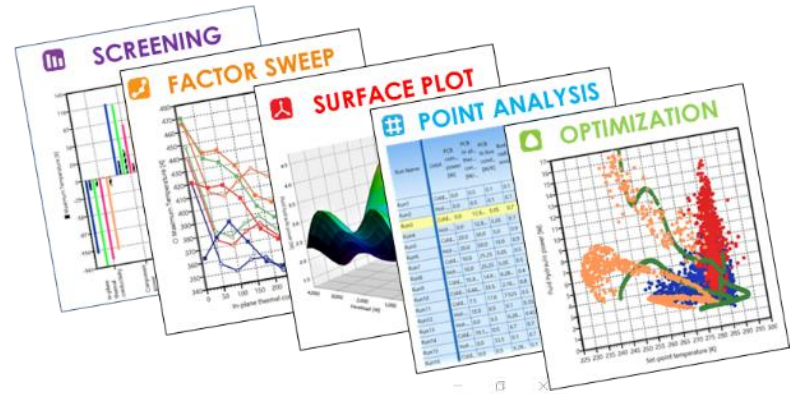


Exploration Tool



Screening Analysis

- Shows relative importance of input factors for a given output response
- Displayed using a Pareto chart bar graph
- Larger bar signifies more impact on the output response



Acknowledgements

Learn More

- Learn more at TFAWS
  - Hands-on session: Tuesday, August 22, 2017 | 3 to 5:00 PM | Med I
- Join an upcoming webinar
  - Tuesday, August 29, 2017: 9 AM MDT
  - Thursday, August 31, 2017: 2 PM MDT
  - Wednesday, September 6, 2017: 9 AM MDT
- Download a free trial from Veritrek.com